2016 LHC Performance Workshop
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Lessons learnt in LHC operation in 2015

G. Papotti (BE-OP-LHC)

with material from and/or thanks to:

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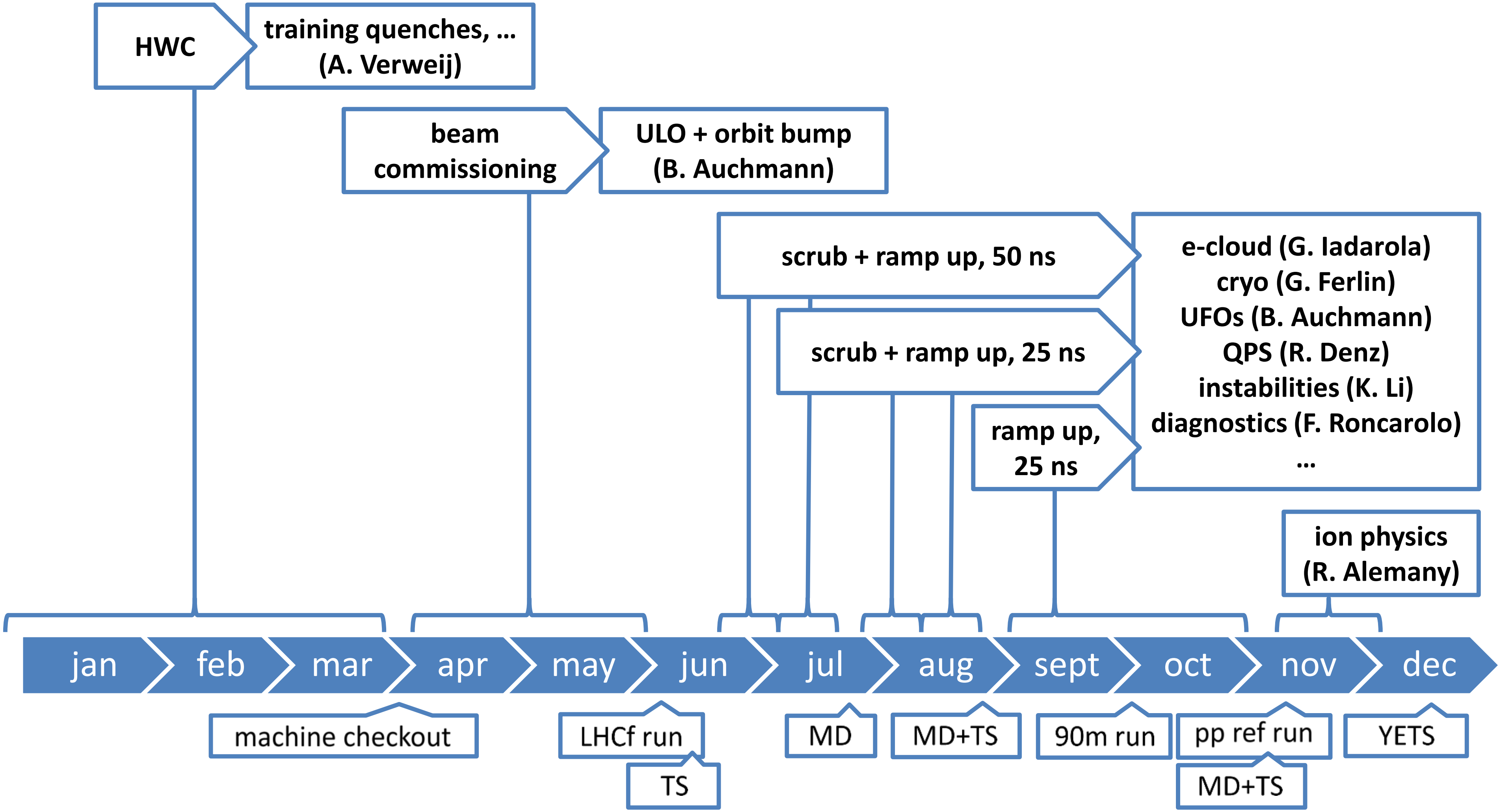
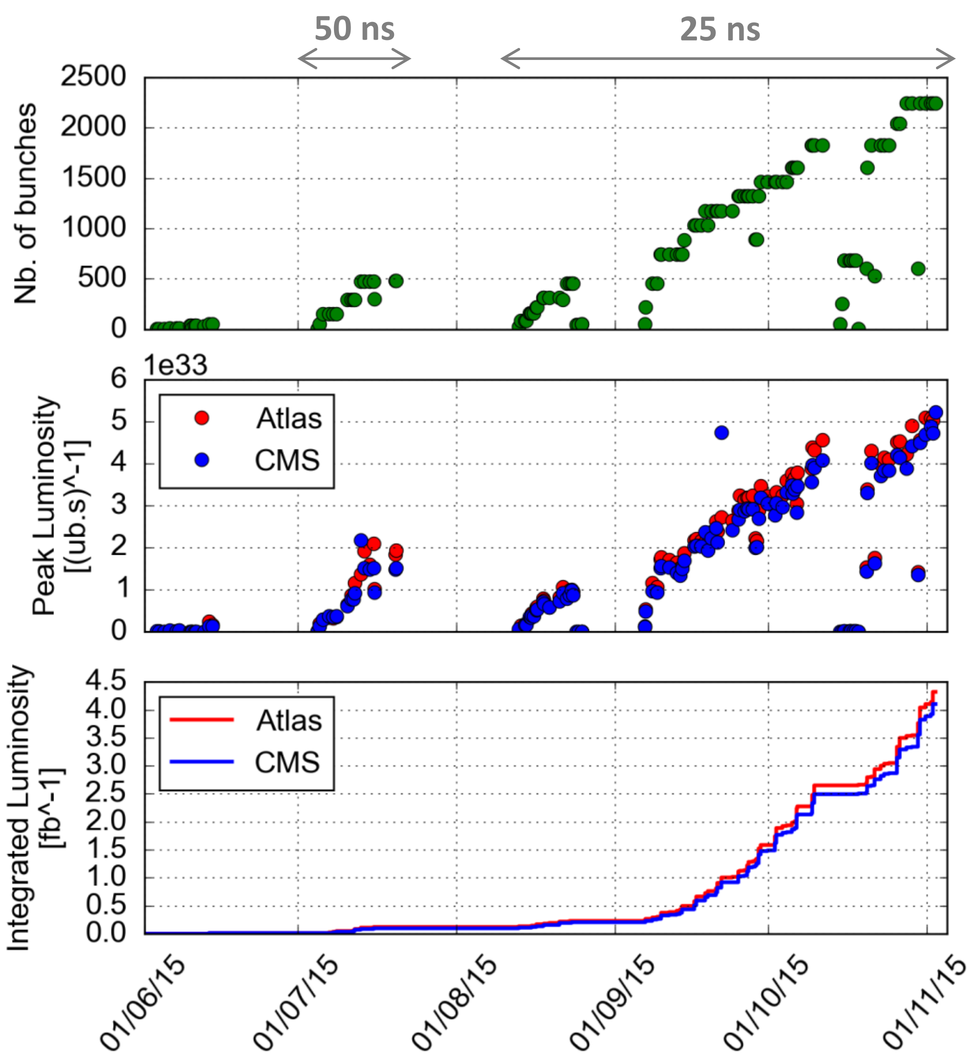
outline

- 2015 timeline
- performance
  - luminosity (peak, integrated, lifetime, optimum fill time)
  - transmission, emittance
  - luminosity equality between IP1 and IP5
- miscellanea
  - injection
  - orbit and Q feedbacks, tune
  - outcomes of MDs

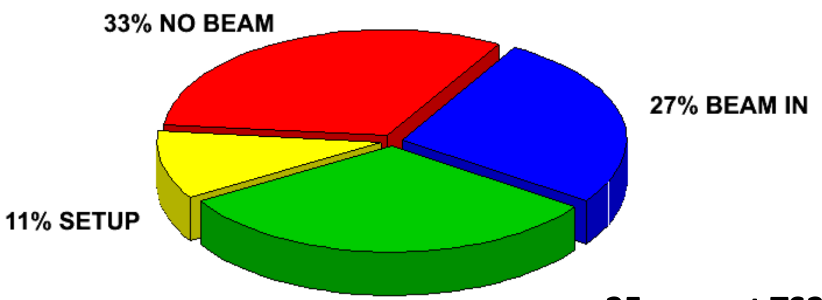
2015 timeline



luminosity history



- invested a lot of time in scrubbing and special physics
- intensity ramp-up lasted until the end
- real production started in September only



25 ns post TS2 (more details by M. Solfaroli)

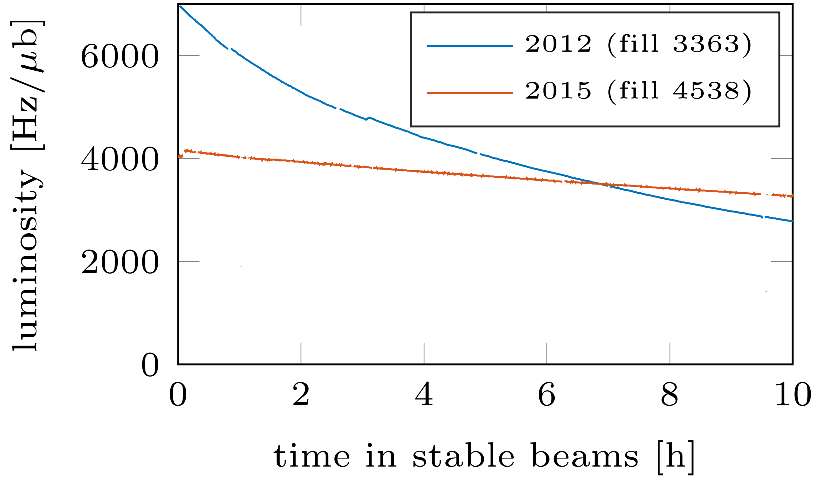
courtesy of G. Iadarola

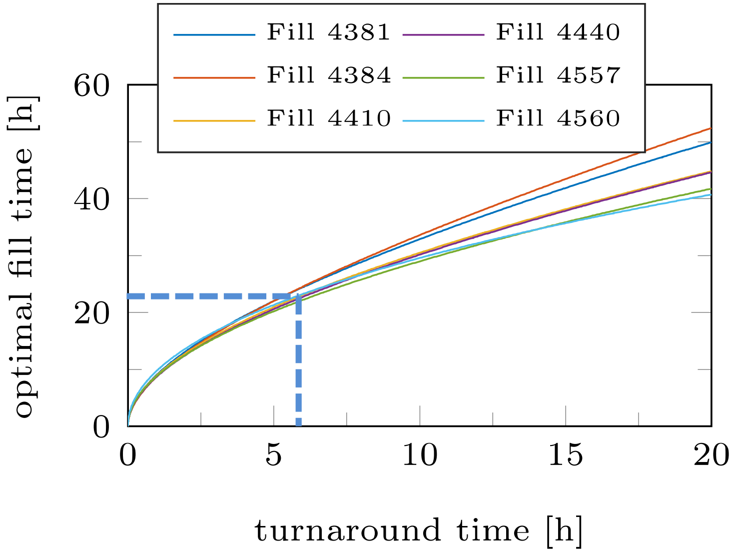
record peak luminosity

	2015	2012
energy [TeV]	6.5	4
bunch spacing [ns]	25	50
beta* [cm] (crossing angle [urad])	80 (290)	60 (290)
e*[mm] at start of fill	3.5	2.5
max. bunch population [10^{11} p/bunch]	1.15	1.6
max. number of bunches/colliding pairs IP1/5	2244/2232	1380
max. stored energy [MJ]	270	140
peak luminosity [10^{34} $cm^{-2}s^{-1}$] in IP1/5	~0.5	>0.7

luminosity lifetime

- very healthy: ~30-40 h
  - high energy
  - synchrotron radiation
  - lower brightness

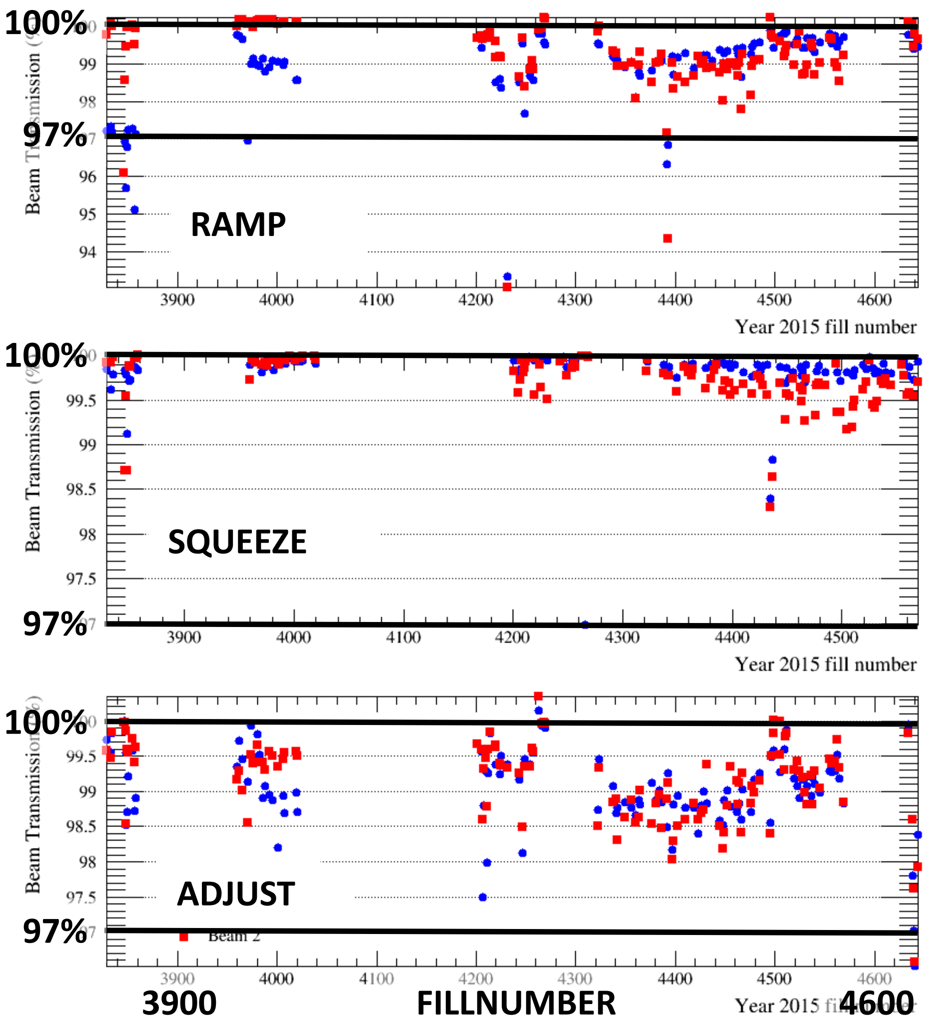




- optimum fill time >20 h for an average turnaround ~6.5 h
  - no OP dumps apart from during intensity ramp up!
  - conclusion still valid for 2016

courtesy of M. Hostettler

transmission through the cycle



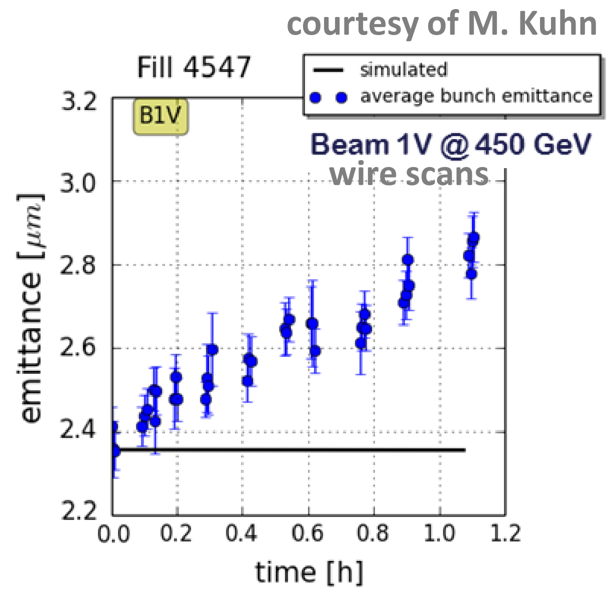
courtesy of B. Salvachua

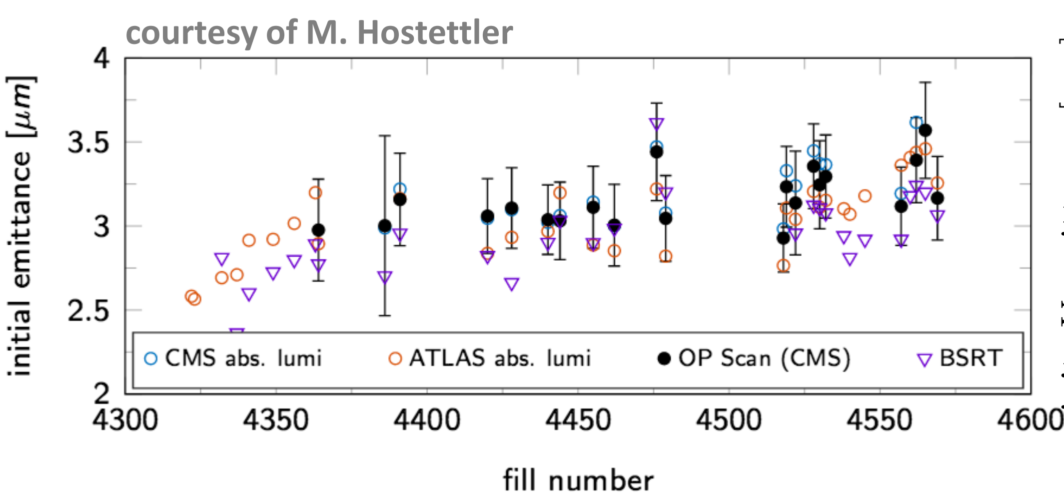
	2011	2012	2015
ramp	99.2/99.8	98.3/98.4	98.9/99.2
squeeze	99.9/99.9	98.8/98.0	99.8/99.7
adjust	99.5/99.7	98.2/98.4	99.1/99.2
total (b1/b2)	99.2/99.3	96.2/95.3	97.8/98.1

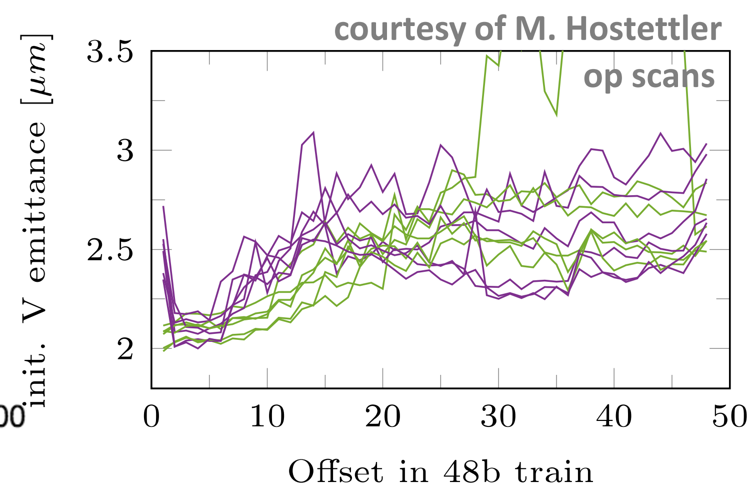
- 2011: negligible losses
- 2012: 4-5% lost before physics
- 2015: ~2%
  - despite high Q’ and octupoles

emittance until collisions

- until collisions, wire scans:
  - IBS is the main source for h growth
  - typical v growth: ~5 % in 10 min.
    - independent of brightness, Q', MO, ADT
- emittance at start of collisions: ~3 μm
  - average growth: ~0.5 μm (25 %)
    - from ATLAS luminosity vs wires at injection
  - BCMS (1 fill!): ~2.5 μm



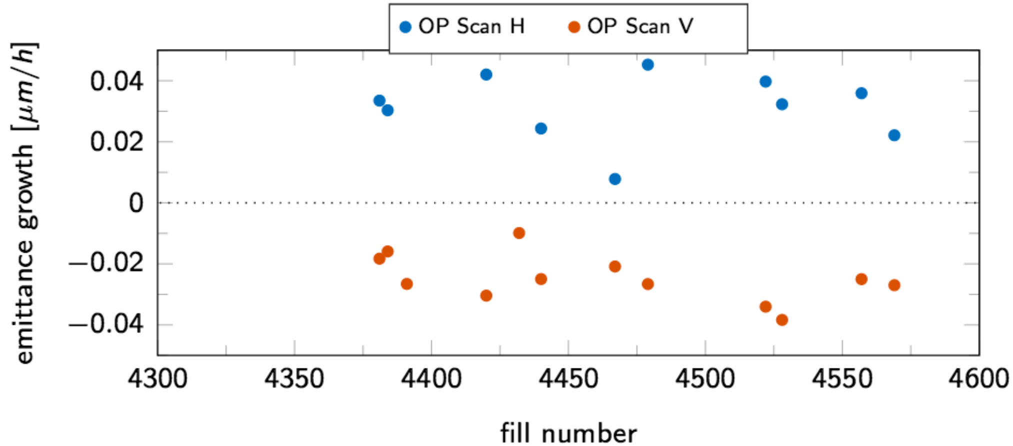




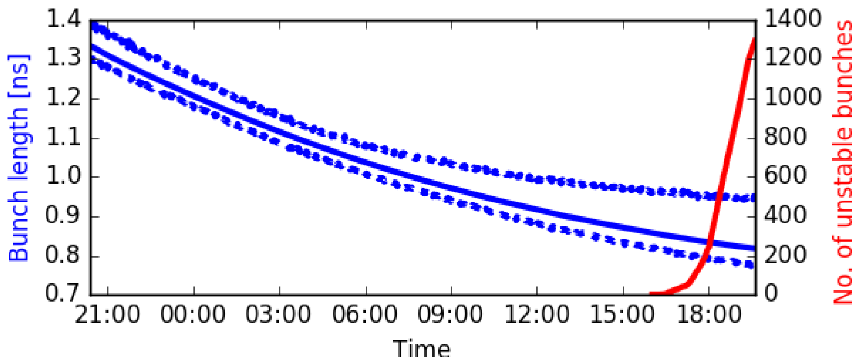
emittance growth in physics

- h growth: ~0.03μm/h
- v shrinkage: ~0.02μm/h
- conv. h/v: constant within errors

- BCMS (only one, 2 h long fill)
  - h increase: 0.1 μm/h
  - v constant



courtesy of M. Hostettler

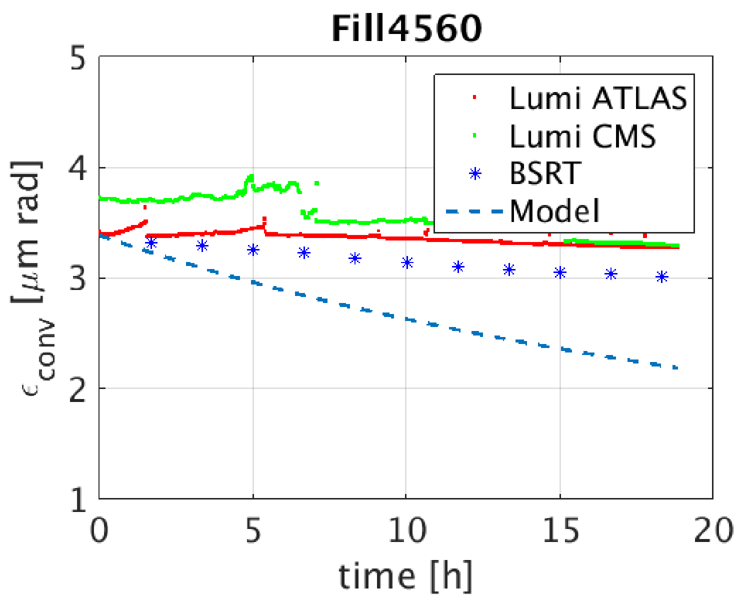


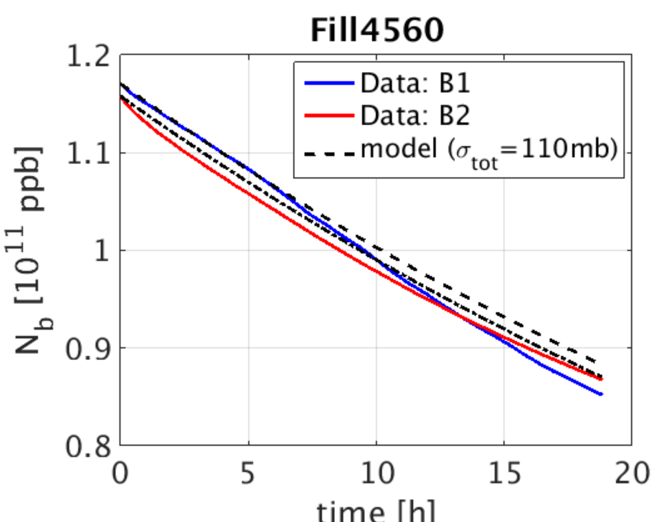
courtesy of J. Esteban Muller

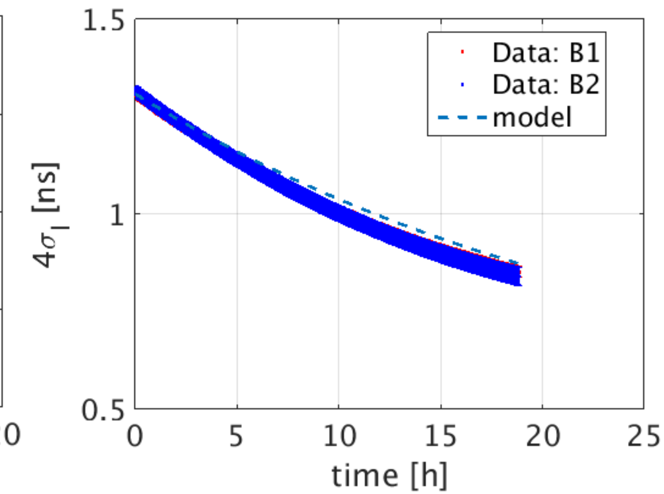
- longitudinal shrinkage also consistent with synchrotron radiation damping
- long fills at the limit of stability
  - bunch flattening available as mitigation

luminosity model

- includes: IBS, synchrotron radiation, burn off in IP1-5
- fully parametrised (one function), bunch-by-bunch
- points to missing components of transverse emittance growth
  - use of measured emittance better matches intensity and longitudinal behaviour



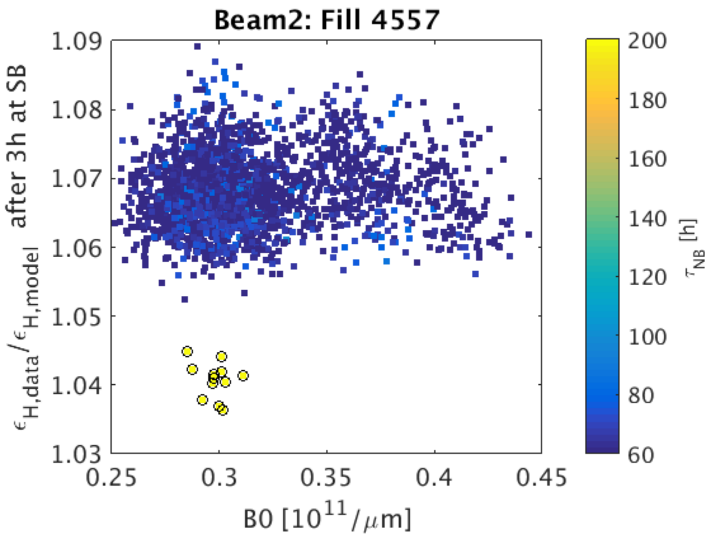


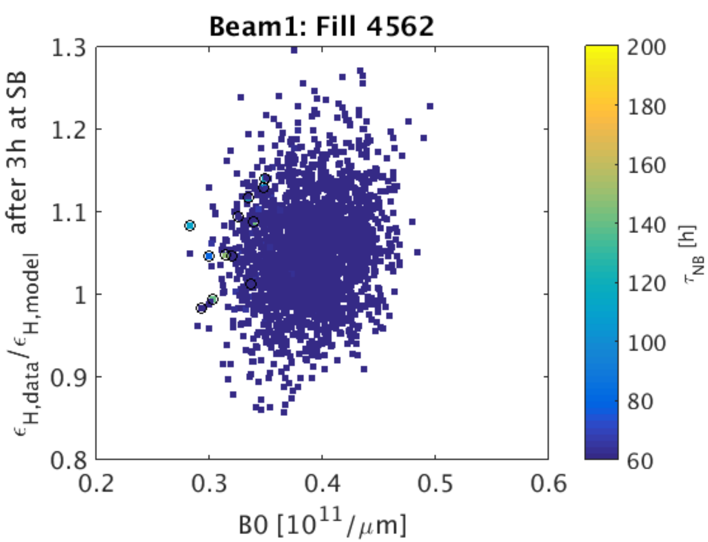


courtesy of F. Antoniou

bunch-by-bunch differences

preliminary

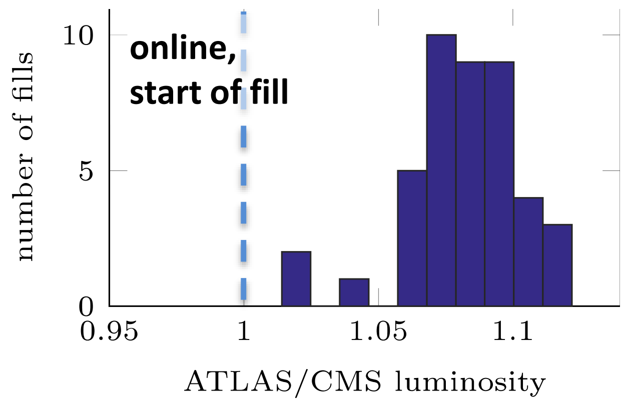


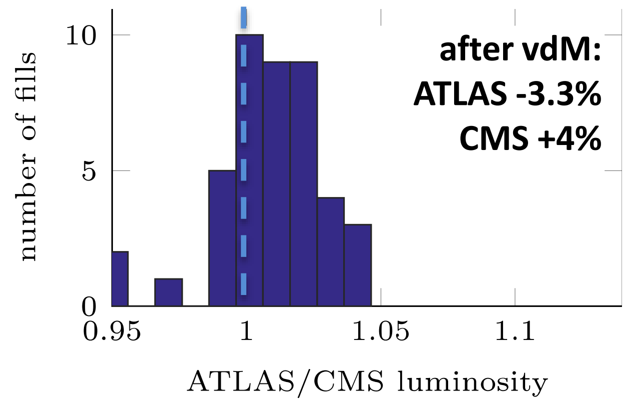


- non colliding bunches added in many fills
  - thanks LPC!
  - much better lifetime (excellent vacuum!)
  - smaller emittance growth, closer to the model
- different fills, different results
  - one "good" example: b2, fill 4557
  - one "bad" example: b1, fill 4562
- ongoing work on understanding the differences (fill-by-fill, bunch-by-bunch)
- important data! continue inserting non-colliding bunches during intensity ramp up
  - as long as there is space
  - as long as no issues with stability
- systematic studies planned

courtesy of F. Antoniou

IP1/5 luminosity difference





courtesy of
M. Hostettler

- the difference triggered additional studies:
  - measured beta at IP: ~84 cm [optics team]
  - waist position off by 20 cm wrt IP [optics team]
  - slightly too big crossing angles: extra 10-20% [J. Wenninger]

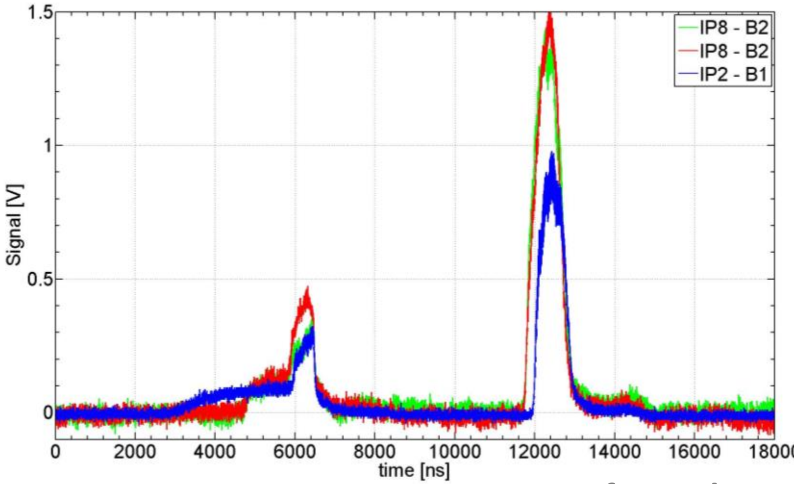
- very important information for the next beam commissionings!
  - optics correction strategy (incl. ballistic optics, k-modulations, …)

MISCELLANEA

D. Jacquet; M. Solfaroli, A. Apollonio

injection

- spend on average 2x min time: still room for improvement
- 2x12 bunch transfer/ring for TL ("steering while filling")
  - 2015: only 1% of time (~20 h) dedicated to injection tuning
  - helped by better trajectory references
- no dumps due to losses, but 144-bunch limit and often got close to dump
  - IQC to use diamond BLMs as extra source of information, and tune thresholds



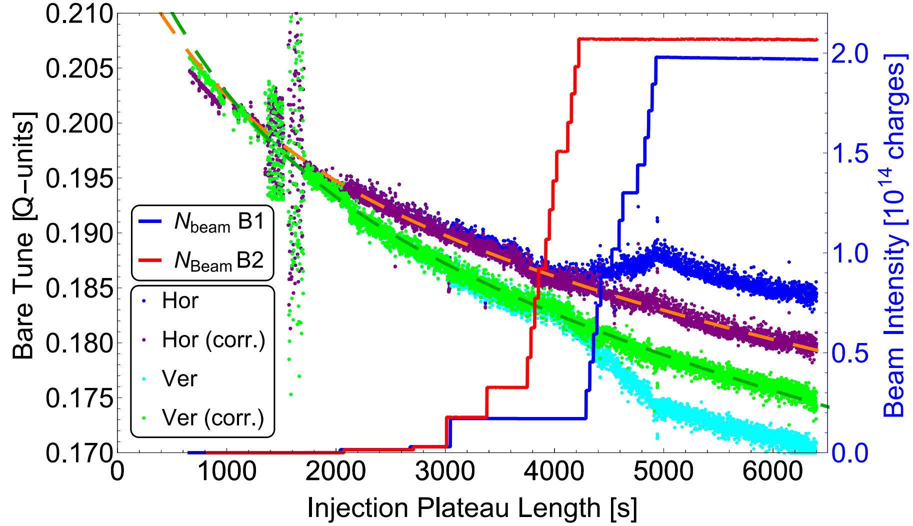
courtesy of F. Burkart

- improved measurements at injection
  - had better Q' measurements
  - automated coupling measurement and correction to come
    - coupling scan in application, and at probe injection
  - wire scanner application: better, but still room for improvement

L. Ponce, M. Schaumann

feedbacks, tune

- QFB used in ramp and squeeze
  - improved Q signals
  - "gated" device solved co-existence with transverse dampers
    - co-existence with abort gap cleaning still a problem in squeeze
- OFB used in stable beams
  - thanks to improved OFB stability and configurability, and BPM signal quality
- decisive for the IR8 triplet movement impact on Stable Beams!
  - R8 triplet movement causes orbit drifts of up to ~0.2 mm rms (period of ~ 8 h, present when triplet filled with Helium, cause not understood yet)
- Q/Q' + snapback well controlled
  - FiDeL + QFB
  - need for precycle questioned
- Q dependence on intensity at inj.
  - e.g. Laslett Q shift
  - ideally automate the correction

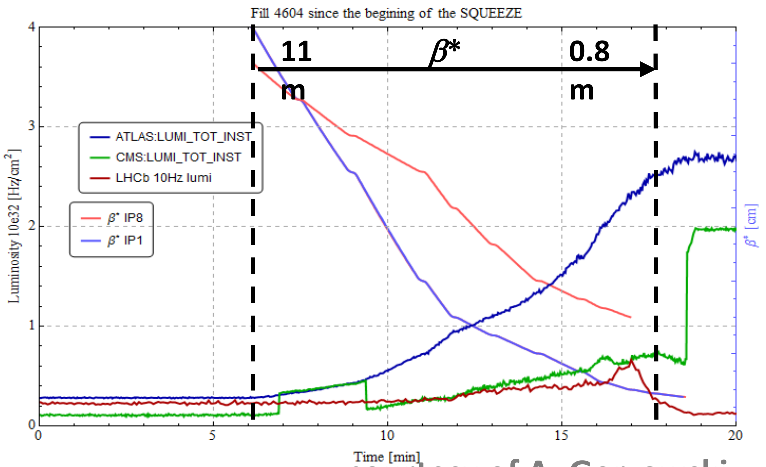


courtesy of M. Schaumann

with R. Tomas, J. Uythoven

(some) outcomes of MDs

- 3x5 days invested in machine studies in 2015
  - organized in 3 prep LSWGs, results in 5 LSWGs
- some highlights of results
  - ?* = 40 cm fully probed and ready for operation in 2016
  - ramp + squeeze commissioned and already used for the 2.51 TeV run
  - β* leveling, and collide + squeeze fully demonstrated
  - quench tests
  - crystal channeling observed at 6.5 TeV
  - new or developed instrumentation: DOROS, BTF, ICT/WCT, Schottky…
  - instability threshold tracked during 2015 and observed to improve with scrubbing



courtesy of A. Gorzawski

conclusion: a long and successful year

- **6.5 TeV**, **25 ns**, 2244 bunches in physics, 80 cm β^*
- despite
  - recovery from LS1 (dipole training, earth faults, …)
  - ULO, QPS, UFOs
  - abundant e-cloud and heat-load for cryo (2016!)
- much improvement gained in the understanding
  - during operation, scrubbing and MDs
  - excellent performance from all systems
- performance:
  - excellent luminosity lifetime
  - excellent transmission through the cycle
  - acceptable emittance growth
    - some causes to be pinned down